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Water Calorimeters and Burning Rates in Flambeau 1967

(plot 760-12 burnt 29.9.67)

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Introduction

1. In an earlier paper (1) it was pointed out that the space variation of burning rate over an array should give a qualitative indication of which mechanism was dominant in any interaction between the piles. It was also found (2) that the time variation of various effects, such as air temperature and thermal radiation, could be roughly represented by a single curve with two undetermined parameters, the peak intensity and the duration.

2. The main type of instrument used by the United Kingdom team for this burn was the Wood Block. This was described by Griffiths and Heselden (3) and the results are reported separately (4). For completeness, however, it was desirable to measure a second parameter.

3. Crudely, the wood blocks respond to $Rt^{1/3}$ (where R is the intensity and t the duration of the thermal pulse); whereas the evaporation of water should respond to Rt. Hence it was hoped to estimate both parameters of the pulse by putting Water Calorimeters alongside the wood blocks.

Method

4. Two types of water calorimeter were used: a Saucepan type, consisting of an Aluminium saucepan about 7" in diameter with 2.17" of water in it buried to the lip in the ground, but separated from the soil by a small air gap, which are reported on in Ref.(4); and a dish type which was an Aluminium foil dish about 6" x 3" x 2" with 1" of water in it. The latter were known as "Brand Traps" because they were originally envisaged for this purpose.

5. Brand traps installed at roof sections (5) were buried to the lip in the ground; the others, mainly at Piazza positions, were simply placed on the ground. All brand traps were fastened to the ground by two skewers.

6. Water was measured out using a plastic measuring cylinder calibrated in ounces. The correct amount was measured out beforehand and then the amount remaining after the burn was recorded - see Table 1.

7. Two brand traps were kept near the base as controls; the readings are shown in Table 2. It can be seen that the loss was considerable, but varied from day to day, doubtless depending on the weather.

8. Based on Table 2, and knowing when each brand trap was last topped up and when measured after the burn, the background correction could be subtracted from the raw readings. The corrected losses, converted to mms. of water, are shown in Table 1.

9. There are obviously substantial errors possible in this. Neither wind, temperature, solar radiation or rainfall were necessarily the same for all brand traps. Both the topping up and the final measurement were, under field conditions, crude. There was at least one instance of a helpful member of another team emptying out a brand trap before the burn, since it had become filled, as he thought, with rainwater! Unfortunately, there was not time to top up all the brand traps the day before the burn, and in the case of a few it is impossible to tell now whether they were topped up then or not. Many brand traps had evaporated to dryness, so that one can only say that the loss is, for example 11+ mms.; when in addition they were last topped up a week before, the calculated loss is probably 0+ mms, which is not very informative.

Results and Discussion

10. Fig 1 shows the space variation of the losses (using Brand traps and Saucepan Types) at Piazza positions. A polynomial surface has been fitted to these results:-

$$\text{Loss in mms} = -0.177x^2 - 0.021x\,y - 0.218\,y^2 + 3.114x + 5.380y - 14.942$$

The coefficients of x^2 and y^2 are not significantly different from one another, nor is that of xy from 0. All other differences are significant. The equation can then be restated:-

$$\text{Loss} = 30 - 0.20\,[(x-8)^2 + (y-12)^2]$$

This is plotted in Fig. 2. Unfortunately, this results in negative losses in the SW corner! The interpretation of Fig. 1 is probably superior, dsepite a certain subjectivity.

11. Fig. 3 shows the space variation over Piazza Positions of the ratio:-

$$\frac{\text{water loss (mms)}}{\text{intensity (watts/cm}^2\text{) from wood blocks with 20 min square pulse}}$$

Following the interpretation of Paragraph 3, this should vary as $t^{2/3}$, or alternatively as (burning rate)$^{-2/3}$. Fig. 3 would then mean that there is an area of low burning rate near the centre of the N side and another near the centre of the E side, but that the burning rate is 2 times faster round the S and W sides, and in the extreme NE corner. This seems a rather unlikely conclusion; it might be explained as a bellows effect due to high wind speed round the edge (Theories 4 of ref(1)), but the wind gauge results (4) suggests that the highest speeds were not there. The average ratio in the piazzas round the insulated pile (Q13) is only 80% of the average ratio in the next ring out; but this is probably just error.

12. Brand traps readings for the 2-pile wide-spaced burn on 28th and the 5-pile burn on 1st are also shown in Table 1, and the 2-pile smoothed results are summarised in Fig. 4. It can be seen that there is a most important wind effect; this was originally assumed to be due to radiation from the leaning flame, but the results of the main burn suggest it may be due to hot air. The higher readings on the outside are probably a statistical artifact, but if real they may be due to the greater indraft wind causing more evaporation. Adding the 4 piazza positions gives an estimated 10 mm loss in a standard piazza position, and this agrees reasonably with the losses round the upwind edges of the main array (Fig. 1), but is only 1/3 of the value at the centre.

13. If the variation of the wood block intensities (about 15 to 1) (4)* were solely due to variation of the local burning rate, then the burning rate would have to vary by about 60 to 1. This is quite incredible. It is inconsistent with the visual observations, and also with the ratios of Fig. 3. (As a further check, if this were so, the burning rates of the weighed piles S9, O5, O9, and J9 should be in the ratio 1 : 1.6 : 2.2 : 4.0.) Hence a large part of the effect must be due to the direct effect of drifting hot gases on the wood blocks. The simple interpretation of Paragraph 3 is therefore probably invalid, particularly since there is probably also a direct effect on water evaporation (see pp 11-12 of ref. (4)). If there were any space variation of burning rate this was probably a fairly minor effect, no more than about a factor of 2.

Application to Firestorms

14. Historical firestorms were marked by an unusually high casualty rate - about 20% at Hamburg. Why was this so?

(1) Due to some sort of interaction between fires, the local burning rate was greatly increased, leading to intolerable local conditions. As shown in Paragraph 13, this can hardly be the major reason.

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* See Fig. 5

(2) There was no interaction - casualties were due simply to trapping. As the fire density is increased, the casualty rate starts to climb steeply when the lethal radius about each fire starts to overlap with its neighbour's. Applying this to terraced housing, assume a man is a casualty if his house, the house opposite the front door, and the house opposite the back door, are all alight.

Hence Casualty rate = $C = p^3$ ....(i)
where p = fraction of houses alight.

For example, if $p = 10\%$, which is reasonable for many group fires, then $C = 0.1\%$, while for $p = 60\%$, which is the order of magnitude of ignitions in Hamburg, $C = 22\%$. Hence this theory could explain the high casualty rate on its own.

(3) Burning rates did not interact, but hot gases drifted across the area with the ambient or indraft wind, and these caused casualties directly, and also by assisting fire spread. So long as the wind is strong enough to keep the plume in contact with the ground the effect (measured as a temperature rise) of a row at distance x upwind is proportional to $1/x$ since the plume from a fire is conical.

Hence T = temperature rise is proportional to $\log n$ ....(ii)
where n is the number of rows upwind.

Alternatively, if fires are a distance d apart on average (i.e. $1/d^2$ fires per unit area), and if each fire gives a crosswind integral k/x at distance x downwind, and the upwind edge is distance D away,

$$T = \frac{k}{d} \log (D/d) \quad \text{..(iii)}$$

15. Since Theory (2) could explain the effect on its own, but it seems that (3) must be operating, it is not possible without further work to estimate their relative importance.

References

(1) A. M. Western "Some simplified theories about mass fires". Proceedings of Mass Fire Research Symposium held DASA, Washington D.C. February 1967. DASIAC special report 59 published October 1967.

(2) A. M. Western "A preliminary analysis of some Flambeau data". As in reference (1).

(3) Lynda G. Griffiths and A. J. M. Heselden "The Use of Wooden Blocks as simple radiometers". As in reference (1).

(4) A. J. M. Heselden and M. J. Wooliscroft "Wood Block and other measurements at Flambeau test fire 760-12". Paper for Sunningdale Symposium.

(5) A. M. Western "The likelihood of fire spread to houses through the roof" Paper for Sunningdale Symposium.

March 1968

Table 1: Brand trap readings and corrected losses

Type of Position	Position (1)	Time topped up (2)	Time (2) Measured	Reading (Oz)	Correcte loss (mms
Piazza (3)	A4	28 AM	30 PM	4	1
"	A8	28 PM	29 1230	4	15
"	A9	28 PM	30 1030	0	19+
"	B4	28 AM	30 1630	0 (13)	-
"	B8	28 PM	30 1030	0 (8)	19+
"	B9	28 PM	"	0 (9)	19+
"	B17	28 PM	30 1200	0	16+
"	C2	28 PM (5)	29 PM	12½	0
"	C16	28 PM	30	0 (11)	16+
"	E8	28 PM	30 1030	0 (9)	19+
"	E9	28 PM	"	0 (8)	19+
"	E17	28 PM	"	0	19+
"	F8	28 PM	"	0 (8)	19+
"	F9	28 PM	"	0 (8)	19+
"	I2	28 PM (5)	29 PM	14	0
"	J1	28 PM (5)	"	8	8
"	J7	28 PM	30 1030	0	19+
"	J8	28 PM	"	½	18
"	J9	28 PM	"	0 (8)(10)	19+
"	J17	28 PM	"	0 (8)(11)	19+
"	K7	28 PM	"	¼	18
"	K8	28 PM	"	0 (8)	19+
"	K9	28 PM	"	0 (8)(10)	19+
"	L6	28 PM (5)	30	0	16+
"	M3	28 PM (5)	30	3	11
"	M15	28 PM	30	0 (9)	16+
"	O4	23 (19)	30 1100	1	3
"	O8	28 PM	"	0	19+
"	O9	28 PM	"	0 (10)	19+
"	P1	23 (19)	29 PM	5	0
"	P5	23 (19)	30 1100	¼	4
"	P8	28 PM	"	2	15
"	P9	28 PM	"	0	19+
"	P11	28 PM (19)	"	1½	16
"	P14	28 PM (19)	"	0	19+
"	P17	28 PM	"	0 (8)	19+
"	Q3	23	30 1100	0	5+
"	Q12	28 PM (19)	"	2½	14
"	Q13	28 PM (19)	30 1130	3½	12
"	Q15	28 PM	30	3	11
"	R11	28 PM (19)	30	1	14
"	R13	28 PM (19)	30 1130	0 (9)(13)	19+
"	S1	23 (19)	29 PM	5	0
"	S8	23 (19)	30 AM	2	0
"	S9	28 PM (19)	29 1145	14	0
"	S12	28 PM	30 1130	6	8
"	S14	28 PM	"	7½	5
"	S17	28 PM	29 PM	14	0
"	T8 (4)	23 (19)	30 AM	7	0
"	T9 (4)	28 PM (19)	29 1145	14	0
Roof (3)	Site 1 posn J	28 PM	30 1015	4½ (10)	11
"	1 K	"	"	2	15
"	1 L	"	"	7	6
"	2 J	"	"	0 (8)	18+
"	2 K	"	"	0 (8)(10)	18+
"	2 L	"	"	0 (9)(10)	18+
"	3 J	"	29 1230	8 (6)(7)	-
"	3 K	"	"	0 (8)	20+
"	3 L	"	"	3 (6)(7)	-

Type of Position	Position (1)	Time topped up (2)	Time (2) Measured	Reading (Oz)	Corrected loss (mms)
Roof (3)	Site 4		29 1200	10½	4
"		" (	"	10½	4
"	4 L				5
"	5 J	"	30 1045	0 (9)(10)	18+
"	5 K	"	"		18+
"	5 L				18+
"	6 J	"	"	0 (8)(10)	18+
"	6 K	"	"	0 (8)	18+
"	6 L				18+
"	7 J	"	"	0 (9)	18+
"	7 K	"	"	0 (9)(10)	18+
"	7 L	"			-
"	8 J	"	"		-
"	8 K	"	"		18+
"	8 L				18+
"	9 J	23 (19)	30 1200	0 (12)	-
"	9 K	" (19)	"	0 (9)	-
"	9 L		"	0 (9)(11)	-
"	10 J	" (19)	29 1145	0	9+
"	10 K	"	"	5	0
"	10 L		"	10	0
"	11 J	"	30 1115	0	-
"	11 K	"	"		-
"	11 L				-
"	12 J	"	"	0 (12)	-
"	12 K	"	"	6	-
"	12 L	"	"	0	-
Radiometer	Foot of T 17	28 AM	29 1230	9	2
Towers (3)	" " T 18	28 PM (5)	29 1200	13	0
Street (3)	Between A11/A12 (gas sample)	23 (19)	30 1200	0 (8)	-
"	Between J11/J12 (NRDL Radiom.)	23 (19)	"	0 (8)	-
Piazza (14)	NW of W pile	28 1330 (15)	28 1515	3	6
" (16)	NE "	"	"	6	1
"	SE "	"	"	5½	2
"	SW "	"	"	6	1
"	NW of E pile	"	"	4	5
"	NE "	"	"	4	5
"	SE "	"	"	6½	0
"	SW "	"	"	6	1
Street (14	W of W pile	"	"	3	6
" (16)	N "	"	"	gone	-
"	E "	"	"	5	3
"	W of E pile	"	"	5½	2
"	N "	"	"	0	12+
"	E "	"	"	3½	5
Control (14)	-	"	"	6½	-
Piazza (17)	A1(3 piles round)	1 0900	1 1320	11½	1
Street (17)	Between Z1/Z2 (18)	"	"	6	11
Control	-	"	"	12	-

Notes for Table 1:-

(1) Piazza positions for the main array are those NE of the pile specified.
(2) The first number is the day of the month (between 23rd September and 1st October).
(3) Main burn of 760-12 on 29th September.
(4) Based on an imaginary row T just south of row S.
(5) Topped up approximately by eye.
(6) Found covered with Miniboard.
(7) With ash.
(8) With dry ash.
(9) With wet ash.
(10) With brands.
(11) Partly melted.
(12) With wet earth.
(13) Driven over and crushed.
(14) 2-pile wide spaced burn of 28th September.
(15) Filled to 7 Oz only.
(16) "Street" positions are 12½' from the side of a pile; "Piazza" positions are 17½' diagonally from the corner, i.e. at the intersection of lines parallel to the pile through the street positions.
(17) 5-pile burn of 1st October.
(18) Z1-Z4 were the 4 extra piles north of A1-A4.
(19) Time of topping up uncertain.

Table 2: Brand Trap Control Readings (Oz)

Date	Time	Control 1	Control 2	Mean loss from 20th
20.9.67	AM	-	14	0
21 9.67	AM	14	-	3
23.9.67	AM	11	9	5
24.9.67	AM	9	7½	6¾
28.9.67	AM	5	3	10½
28.9.67	PM	2/14*	1/14*	13
29.9.67	1220	12	13	14¼
30.9.67	1000	9½	11	16¾
1.10.67	AM	5	7	21

* Controls topped up afresh to 14 Oz.

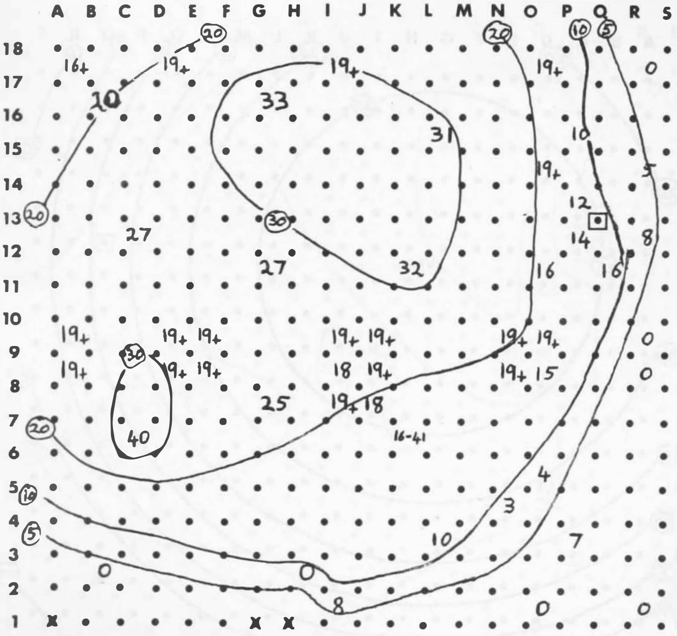

Fig. 1: Evaporation in mms - observed

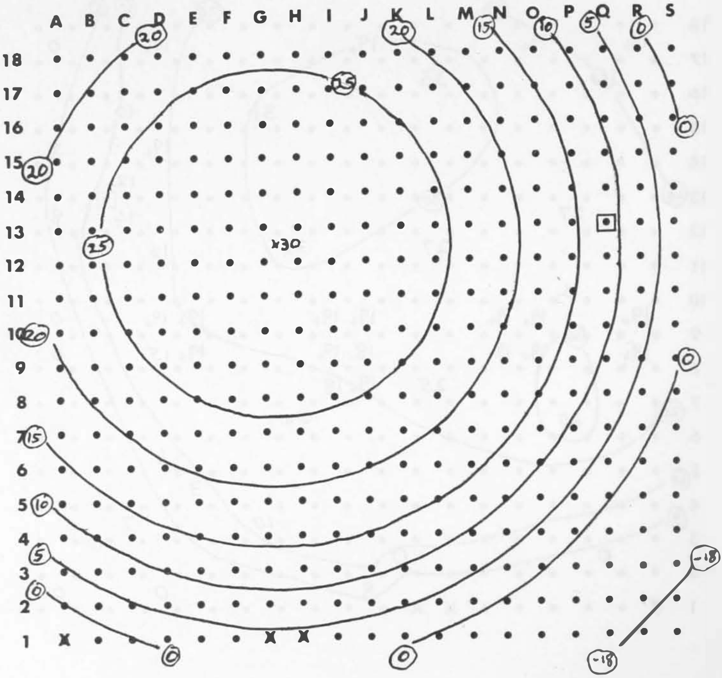

Fig. 2: Quadric surface fitted to water evaporations

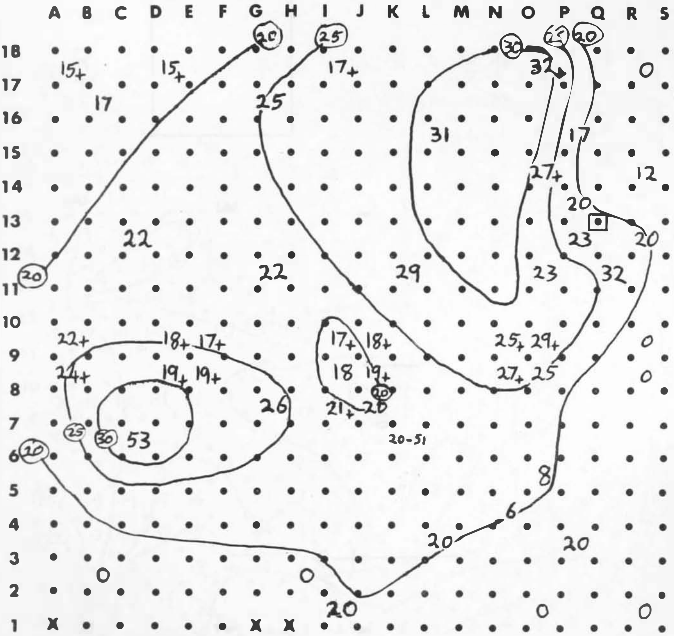

Fig. 3: Ratio: $\frac{\text{Evaporation}}{\text{Wood block intensity}}$

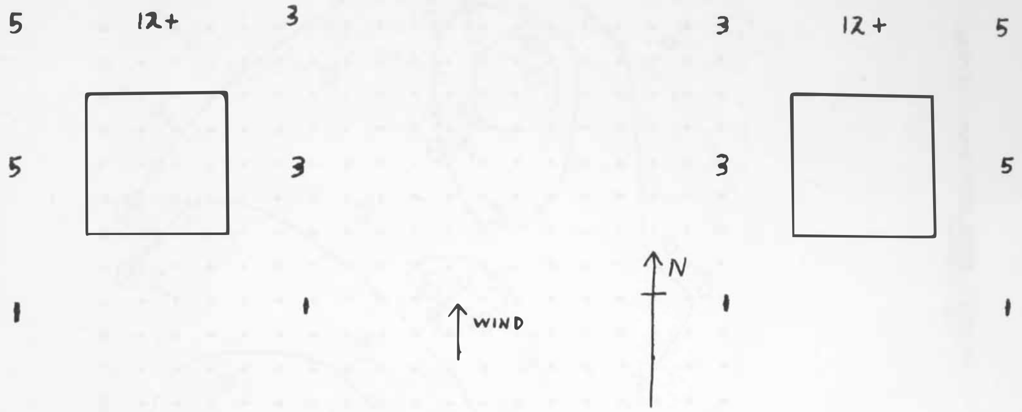

Fig. 4 Smoothed corrected losses in mms. 2 - pile wide spaced burn (28/9/67)

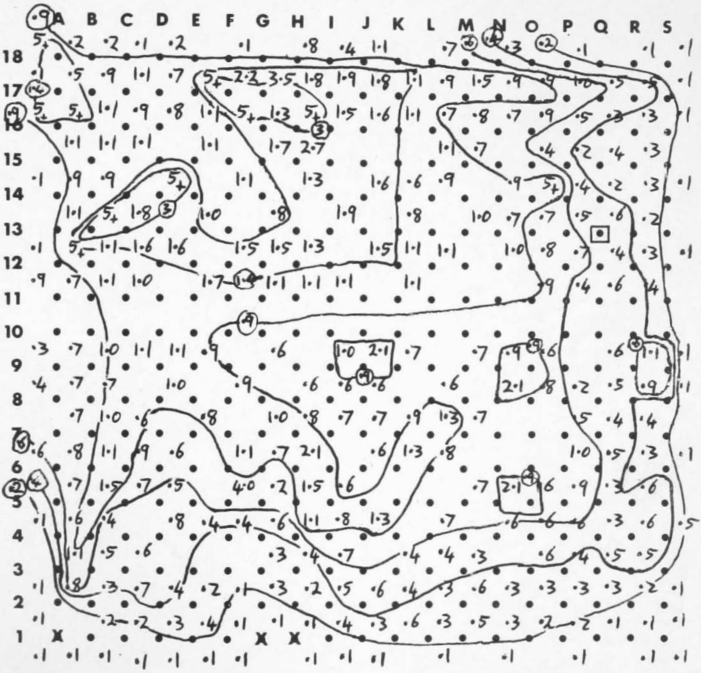

Fig. 5: Wood Block Intensities - watts/cm^2